

WHAT SHOULD THE FeO CONTENT OF A TERRESTRIAL PLANET BE? J.H. Jones, KR, NASA/JSC, Houston, TX 77058 (john.h.jones@nasa.gov)

Core Formation in the Terrestrial Planets: Basalts from the Earth, the Moon, Mars, and Vesta are strongly depleted in elements that prefer to reside in the metallic state (siderophile elements). Therefore, it is believed that all these bodies have metallic cores. We do not yet have siderophile element analyses of venusian or mercurian basalts, but we assume that Venus, too, as a terrestrial planet, has a metallic core. For the Earth, Moon, Mercury, and Mars, the moments-of-inertia of these bodies are consistent with metallic cores of various sizes. Because Venus rotates so slowly, it may be difficult to determine the moment-of-inertia of Venus in order to confirm this assumption. However, despite many possible complexities, it seems likely that most of the major and minor terrestrial planets have experienced some sort of metal/silicate equilibration, and we will use this as a boundary condition.

Experimental Constraints: The fundamental experimental constraint on core formation at low pressure comes from the work of Stolper [1] on eucrites, which contain ~18 wt.% FeO. He found that, in order to saturate eucritic liquids with metallic iron, it was necessary to achieve oxygen fugacities of ~IW-1 (a log unit below the iron-wüstite oxygen buffer). This makes good physical-chemical sense. Eucrites are not wüstite-saturated, do not crystallize wüstite, and therefore require redox conditions significantly below the IW buffer before they can come into equilibrium with metallic iron.

A second fundamental experimental constraint comes from Walker et al. [2], who noted that lunar mare basalt compositions that were experimented on in pure iron capsules at 1-bar to 30-kbar did not gain or lose FeO. This implies that lunar basalts are nearly saturated in metallic iron at about IW-1. This is corroborated by the frequent presence of metallic iron in the mesostases of lunar mare basalts [3].

Finally, Jurewicz et al. [4] found that partial melts of chondrites held at IW-1 [one-bar gas-mixing] contained about 18 wt.% FeO and were compositionally extremely similar to eucrites.

Therefore, the origin of basalts with 18-20 wt.% FeO seems well constrained at low pressure. They require redox conditions of ~IW-1.

Generalizations: Both lunar basalts and eucrites have the general property that they have FeO contents of ~18-20 wt.%. Combining the work of [1,2,4], it seems clear that, at low pressure (< 50 kbar), planets

such as the Moon and Vesta conspire to produce basalts with 18-20 wt.% FeO if their source regions were in equilibrium or near-equilibrium with iron metal at IW-1.

A third planet that produces basalts with 18-20 wt.% FeO, and which is known to have a metallic core, is Mars. We know the FeO content of martian basalts by analyses of martian meteorites, and we know that Mars has a metallic core from its moment of inertia. By inference therefore, it is likely that martian basalts also come from source regions that once had an oxygen fugacity of ~IW-1. Oxygen fugacity measurements on primitive martian meteorites confirm this inference. Spinel-ilmenite assemblages in primitive martian meteorites yield oxygen fugacities in the vicinity of IW [5] and these oxygen fugacities should be upper limits to that of the source regions of these basalts [6].

Therefore, the Moon, Mars, and Vesta are consistent with low pressure (< 30 kbar) experiments that constrain the initial conditions of core formation on these bodies to have been at ~IW-1, with the subsequent production of basalts that have 18-20 wt.% FeO. Also, this is approximately the f_{O_2} calculated from an equilibrated ordinary chondrite assemblage.

The Earth and Venus: Two exceptions to this self-consistent picture are the Earth and Venus. Basalts on these planets have FeO contents of 8-10 wt.% [7] — roughly half that of the “self-consistent” group. The most assured difference between the Earth and Venus on the one hand and the “self-consistent” terrestrial planets on the other is size and mass. Mars is the largest “self-consistent” planet and it may generate core-mantle-boundary pressures in the vicinity of 250 kbar [8]. Alternatively, the Earth and Venus may have core-mantle pressures of ~1400 kbar [9].

This observation suggests that the Earth and Venus have FeO contents that are dominated by high-pressure, rather than low-pressure, equilibria. Various authors have speculated on the cause of the FeO content of the Earth’s mantle, but common themes have been to ascribe the Earth’s FeO abundance either to pressure [e.g., 10] or to heterogeneous accretion [e.g., 11].

Perhaps the strongest argument against heterogeneous accretion is that most terrestrial bodies, i.e., the Moon, Mars and Vesta, do not manifest any indication of such. For example, the Moon, which appears to have formed in proximity to the Earth, has the FeO content and oxygen fugacity that would be predicted

from eucrite experiments [1]. Therefore, there is at least circumstantial evidence that the FeO contents of the Earth and Venus are determined by high pressure equilibria [10].

Mercury: The recent MESSENGER results indicate that Mercury is another outlier from the “self-consistent group.” Mercury also appears to have low FeO basalts [12] but this cannot be ascribed to high pressure. Both the low FeO and high S of the mercurian surface strongly suggests that, for whatever reason, Mercury is a highly reduced planet, much like E-chondrites and aubrites.

Just as we used commonality of fo_2 to link the Moon, Mars, and Vesta, we use a non-commonality to set Mercury apart. Note that this argument does not apply to the Earth, which is, if anything, more oxidized than the “self-consistent group.” The oxidation state of Venus is not well known, but the abundance of CO_2 would argue against extremely reducing conditions.

Mechanisms?: The simplest mechanism for reducing the FeO content of an oxidized, Earth-sized body is for FeO to become soluble in liquid iron metal at the core-mantle boundary [10]. In other words, the core could become a sink for FeO, reducing the FeO content of the mantle. Other, solid-state reactions, interior to the mantle, require transport of FeO-bearing metal out of the mantle and into the core.

Implications for the Giant Impact Origin of the Moon: One immediate contrast between the Earth and Moon is the difference in FeO content between lunar and terrestrial basalts. Both bodies presumably formed near 1 AU and formed from the same feeding zone of planetesimals, judging by their oxygen isotopes [13]. If, for example, the Moon formed from the Earth by a giant impact, then this event must have occurred before high-pressure equilibria had the opportunity to deplete the Earth’s mantle in FeO. Alternatively, the bulk silicate Moon may be dominated by material from the impactor. Regardless, it would be useful to know the pressures where FeO incorporation into a metallic core is not of interest. If the Giant Impact hypothesis is correct, this should set an upper limit for the size of the proto-Earth at the time of the impact.

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